

We Claim:

1. A method of verifying a logic design for proper operation of tri-state buses specified in the design, the method comprising:
for each bus in the circuit design, performing an exhaustive analysis on a min-cut set of logic controlling the bus and designating each said bus as either conclusively conflict-free and float-free or as inconclusive.
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2. A method as defined in claim 1, further including performing a full exhaustive analysis of the bus when the exhaustive analysis on the min-cut set of logic is inconclusive.
3. A method as defined in claim 1, said performing an exhaustive analysis on a min-cut set further including:
determining a min-cut set of logic elements having the smallest size, said min-cut set being a
cut-set of logic elements which separates the control logic cone of the bus into two
parts in which all paths between a logic element in one part and a logic element in
the other part pass through an element in the min cut-set of logic elements;
5 determining the inputs of the min-cut set of logic elements;
for each of a plurality of combinations of logic values:
assigning the combination of logic values to the inputs of the min-cut set of logic
elements;
10 forward simulating the logic values from said inputs to the select inputs of each tri-state gate of the bus under test so as to determine the input of each said tri-state to said bus;
determining whether a bus-conflict or a floating bus condition exists; and
15 designating said min-cut set exhaustive analysis as inconclusive when a conflict or floating condition exists and
designating said bus as conflict-free and float-free when no conflict condition has been determined after all of said plurality of combinations of logic values have been evaluated.
4. A method as defined in claim 3 said assigning the combination of logic values including generating a random set of logic values.

5. A method as defined in claim 2, said full exhaustive analysis comprising:
determining the inputs of the logic cone of the select inputs of the tri-state gates of the bus under test;
for each of a plurality of combinations of logic values:
- 5 assigning the combination of logic values to said inputs of said logic cone;
forward simulating said logic values from said logic cone inputs to the select inputs of each tri-state gate of the bus under test so as to determine the input of each said tri-state gate to said bus;
determining whether a bus-conflict or a floating bus condition exists;
- 10 designating said bus as a conflict bus when a bus-conflict or floating bus condition exists;
designating said bus as a conflict-free and float-free bus when no bus-conflict or floating bus condition has been determined after evaluating all of said plurality of combinations of logic values.
6. A method as defined in claim 5, said assigning the combination of logic values including generating a random set of logic values.
7. A method as defined in claim 1, further including performing pre-analysis processing comprising:
identifying all buses in said circuit design; and
arranging identified buses in sorted list for processing in which buses in the fan-in of other
- 5 buses appear earlier in the list than the other buses.
8. A method as defined in claim 7, said pre-analysis processing including mapping any non-scanned pipeline flops as buffers before analyzing the buses.
9. A method as defined in claim 7, said pre-processing including:
applying constant logic values on one or more inputs of said circuit, including assigning and propagating said constant logic values; and
maintaining constant throughout said analyses said constant logic values and logic values
- 5 resulting from said propagating.
10. A method as defined in claim 5, said forward simulating including performing a parallel application of said combinations of logic values in which multiple combinations are evaluated simultaneously by using each bit of an integer to store one combination.

11. A method of verifying a logic design for proper operation of tri-state buses specified in the design, the method comprising:

identifying all buses in said circuit design;

arranging identified buses in a sorted list for processing in which buses in the fan-in

5 of other buses appear earlier in the list than the other buses; and

for each bus in said list:

performing an exhaustive analysis on a min-cut set of logic controlling the bus, said performing an exhaustive analysis on a min-cut set further including:

10 determining a min-cut set of logic elements having the smallest size, said min-cut set being a cut-set of logic elements which separates the control logic cone of the bus into two parts in which all paths between a logic element in one part and a logic element in the other part pass through an element in the min-cut set of logic elements;

determining the inputs of the min-cut set of logic elements; and

15 for each of a plurality of combinations of logic values:

assigning the combination of logic values to the inputs of said min-cut set of logic elements;

forward simulating the logic values from said inputs to the select inputs of each tri-state gate of the bus under test so as to
20 determine the input of each said tri-state to said bus;

determining whether a bus-conflict or a floating bus condition exists; and, if so, designating said min-cut set exhaustive analysis as inconclusive and performing a full exhaustive analysis of the bus; and

25 designating said bus as conflict free and float-free when no conflict conditions have been determined after evaluating all of said combinations of logic values.

12. A method as defined in claim 11, said forward simulating including performing a parallel application of said combinations of logic values in which multiple combinations are evaluated simultaneously by using each bit of an integer to store one combination.

13. A method as defined in claim 11, said full exhaustive analysis comprising:
determining the inputs of the logic cone of the select inputs of the tri-state gates of the bus
under test;

for each of a plurality of combinations of logic values:

- 5 assigning the combination of logic values to said inputs of the logic cone;
 forward simulating the logic values from said logic cone inputs to the select inputs of
 each tri-state gate of the bus under test so as to determine the input logic
 value of each said tri-state gate to said bus;
 determining whether a bus-conflict or a floating bus condition exists;
- 10 designating said bus as a conflict bus when a conflict or floating condition
 exists;
designating said bus as a conflict-free and float-free bus when no bus-conflict or floating
condition has been determined after evaluating all of said plurality of combinations of
logic values.

14. A method as defined in claim 13, said forward simulating including performing a
parallel application of said combinations of logic values in which multiple combinations are
evaluated simultaneously by using each bit of an integer to store one combination.

15. A method as defined in claim 1, further including, prior to performing an exhaustive
analysis on a min-cut set of logic controlling the bus:
performing an implication based conflict-free analysis on said bus to determine whether said
bus is conflict-free;

- 5 performing an implication based floating-free analysis on said bus to determine whether said
 bus is floating-free; and
designating said bus as a no-conflict bus when said bus is determined to be conflict-free and
floating free and selecting a next bus in sequence for analysis.

16. A method as defined in claim 15, said performing an implication based conflict-free analysis on said bus to determine whether said bus is conflict-free, comprising:
for each input of the bus:

- 5 implying logic values to signals which control the control input of the tri-state gate
 associated with said each input so as to produce an enabling control value;
 determining whether said implying logic values results in an implication conflict;
 when an implication conflict exists, selecting another of said inputs and
 repeating said implying and determining steps;
 when an implication conflict does not exist, determining whether said
10 implying logic values results in a bus conflict;
 terminating said implication based conflict-free analysis and
 performing a full exhaustive analysis when a bus
 conflict is determined;
 determining whether all other inputs to said bus are in a high impedance state and, if
15 not, terminating said implication based conflict-free analysis and performing
 an exhaustive analysis on a min-cut set of logic controlling the bus; and
designating said bus as conclusively conflict-free when each said implying logic values
resulted in either an implication conflict all other inputs to said bus being in a high
impedance state.

17. A method as defined in claim 15, said performing an implication based floating-free analysis on said bus to determine whether said bus is floating-free, comprising:

- implying logic values to signals which control the control input of each tri-state gate
associated with said bus so as to produce disabling control value on the control
5 inputs of said gates;
determining whether said implying logic values results in an implication conflict;
terminating said implication based floating-free analysis and performing an exhaustive
analysis on a min-cut set of logic controlling the bus when no implication conflict is
determined; and
10 designating said bus as floating-free when an implication conflict is determined.

18. A method as defined in claim 17, said performing an implication based conflict-free analysis on said bus to determine whether said bus is conflict-free, comprising:
for each input of said bus which is controlled by a tri-state gate having a select input;
initializing the circuit to unknown values;
- 5 assigning an enabling value to the select input of the bus;
 implying logic values to inputs to said gate needed to produce an enabling value;
 determining whether said implying logic values results in an implication conflict and
 selecting a next input for analysis when an implication conflict is detected;
 determining whether a bus conflict exists at the inputs of said bus and
- 10 performing a full exhaustive analysis of said bus when a bus conflict exists;
 when no bus-conflict exists,
 determining whether all other inputs of said bus are in a high-
 impedance state and, if not, performing said exhaustive
 analysis on a min-cut set of logic controlling the bus, and, if
- 15 so, selecting a next input for analysis; and
 designating said bus as conclusively conflict-free when each said implying logic values
 resulted in either an implication conflict all other inputs to said bus being in a high
 impedance state.

19. A method of verifying a logic design for proper operation of tri-state buses specified in the design, the method comprising, for each bus in the circuit design:
performing an implication based conflict-free analysis on said each bus to determine whether said bus is conflict-free;
5 performing an implication based floating-free analysis on said bus to determine whether said bus is floating-free; and
designating said bus as a no-conflict bus when said each bus is determined to be conflict-free and floating free; and
performing an exhaustive analysis of the bus when either of said implication based analyses
10 is inconclusive.
20. A method as defined in claim 19, said performing an implication based conflict-free analysis on said bus to determine whether said bus is conflict-free, comprising:
for each input of the bus:
5 implying logic values to signals which control the control input of the tri-state gate associated with said each input so as to produce an enabling control value;
determining whether said implying logic values results in an implication conflict;
when an implication conflict exists, selecting another of said inputs and
repeating said implying and determining steps;
when an implication conflict does not exist, determining whether said
10 implying logic values results in a bus conflict and terminating said
implication based conflict-free analysis and performing a full
exhaustive analysis when a bus conflict is determined;
determining whether all other inputs to said bus are in a high impedance state and, if
not, terminating said implication based conflict-free analysis and performing
15 an exhaustive analysis on a min-cut set of logic controlling the bus; and
designating said bus as conclusively conflict-free when each said implying logic values
resulted in either an implication conflict all other inputs to said bus being in a high
impedance state.

21. A method as defined in claim 19, said performing an implication based, floating-free analysis on said bus to determine whether said bus is floating-free, comprising:
implying logic values to signals which control the control input of each tri-state gate
associated with said bus so as to produce disabling control value on the control
5 inputs of said gates;
determining whether said implying logic values produces an implication conflict;
terminating said implication based floating-free analysis and performing an
exhaustive analysis on said bus when no implication conflict is determined;
and
10 designating said bus as floating-free when an implication conflict is determined.

22. A method as defined in claim 20, said performing an implication based, floating-free analysis on said bus to determine whether said bus is floating-free, comprising:
implying logic values to signals which control the control input of each tri-state gate
associated with said bus so as to produce disabling control value on the control
5 inputs of said gates;
determining whether said implying logic values produces an implication conflict;
terminating said implication based floating-free analysis and performing an
exhaustive analysis on a min-cut set of logic controlling the bus when no
implication conflict is determined; and
10 designating said bus as floating-free when an implication conflict is determined.

23. A method as defined in claim 19, said exhaustive analysis including an exhaustive analysis on a min-cut set of logic controlling the bus.

24. A method as defined in claim 23, said exhaustive analysis on a min-cut set including:
determining a min-cut set of logic elements having the smallest size, said min-cut set being a
cut-set of logic elements which separates the control logic cone of the bus into two
parts in which all paths between a logic element in one part and a logic element in
the other part pass through an element in the min cut-set of logic elements;
5 determining the inputs of the min-cut set of logic elements;
for each of a plurality of combinations of logic values:
assigning the combination of logic values to the inputs of the min-cut set of logic
elements;
10 forward simulating the logic values from said inputs to the select inputs of each tri-
state gate of the bus under test so as to determine the input of each said tri-
state to said bus;
determining whether a bus-conflict or a floating bus condition exists; and
designating said min-cut set exhaustive analysis as inconclusive when a
15 when a conflict or floating condition exists and
designating said bus as conflict-free and float-free when no conflict condition has been
determined after all of said plurality of combinations of logic values have been
evaluated.
25. A method as defined in claim 24, said forward simulating including performing a
parallel application of said combinations of logic values in which multiple combinations are
evaluated simultaneously by using each bit of an integer to store one combination.
26. A method as defined in claim 23, said exhaustive analysis being a full exhaustive
analysis including:
determining the inputs of the logic cone of the select inputs of the tri-state gates of the bus
under test;
5 for each of a plurality of combinations of logic values:
assigning the combination of logic values to said inputs of the logic cone;
forward simulating the logic values from said logic cone inputs to the select inputs of
each tri-state gate of the bus under test so as to determine the input of each
said tri-state gate to said bus;
10 determining whether a bus-conflict or a floating bus condition exists; and
designating said bus as having a no conflict bus when no conflict or floating condition exists
and designating said bus as a conflict bus when a conflict or floating condition exists.

27. A method of verifying a logic design for proper operation of tri-state buses specified in the design, the method comprising, for each bus in the circuit design:
performing an implication based conflict-free analysis on said each bus to determine whether said bus is conflict-free;
performing an implication based floating-free analysis on said bus to determine whether said bus is floating-free; and
designating said bus as a no-conflict bus when said bus is determined to be conflict-free and floating-free and performing an exhaustive analysis of the bus when either of said implication based analyses is inconclusive.

28. A method as defined in claim 27, said performing an exhaustive analysis including an exhaustive analysis on a min-cut set of logic controlling the bus.

29. A method as defined in claim 28, said performing an exhaustive analysis including performing a full exhaustive analysis of the bus when the exhaustive analysis on the min-cut set of logic is inconclusive.

30. A method as defined in claim 29, said exhaustive analysis on a min-cut set including:
determining a min-cut set of logic elements having the smallest size, said min-cut set being a cut-set of logic elements which separates the control logic cone of the bus into two parts in which all paths between a logic element in one part and a logic element in the other part pass through an element in the min cut-set of logic elements;
determining the inputs of the min-cut set of logic elements;
for each of a plurality of combinations of logic values:

assigning the combination of logic values to the inputs of the min-cut set of logic elements;

forward simulating the logic values from said inputs to the select inputs of each tri-state gate of the bus under test so as to determine the input of each said tri-state to said bus;

determining whether a bus-conflict or a floating bus condition exists; and

designating said min-cut set exhaustive analysis as inconclusive when a conflict or floating condition exists and

designating said bus as conflict-free and float-free when no conflict condition has been determined after all of said plurality of combinations of logic values have been evaluated.

31. A method as defined in claim 30, said performing an implication based conflict-free analysis on said bus to determine whether said bus is conflict-free comprising:
for each input of the bus:

5 implying logic values to signals which control the control input of the tri-state gate
 associated with said each input so as to produce an enabling control value;
 determining whether said implying logic values results in an implication conflict;
 when an implication conflict exists, selecting another of said inputs and
 repeating said implying and determining steps;
 when an implication conflict does not exist, determining whether said
10 implying logic values results in a bus conflict;
 terminating said implication based conflict-free analysis and
 performing a full exhaustive analysis when a bus
 conflict is determined;
 determining whether all other inputs to said bus are in a high impedance state and, if
15 not, terminating said implication based conflict-free analysis and performing
 said exhaustive analysis on a min-cut set of logic controlling the bus; and
designating said bus as conclusively conflict-free when each said implying logic values
resulted in either an implication conflict all other inputs to said bus being in a high
impedance state.

32. A method as defined in claim 31, said performing an implication based floating-free analysis on said bus to determine whether said bus is floating-free comprising:
initializing the circuit to unknown values;
implying logic values to signals which control the control input of each tri-state gate
5 associated with said bus so as to produce disabling control value on the control
 inputs of said gates;
determining whether said implying logic values produces an implication conflict;
 terminating said implication based floating-free analysis and performing an
 exhaustive analysis on a min-cut set of logic controlling the bus when no
10 implication conflict is determined; and
designating said bus as floating-free when an implication conflict is determined.

33. A method as defined in claim 32, said full exhaustive analysis including:
determining the inputs of the logic cone of the select inputs of the tri-state gates of the bus
under test;

for each of a plurality of combinations of logic values:

- 5 assigning the combination of logic values to said inputs of the logic cone;
 forward simulating the logic values from said logic cone inputs to the select inputs of
 each tri-state gate of the bus under test so as to determine the input of each
 said tri-state gate to said bus;
 determining whether a bus-conflict or a floating bus condition exists;
- 10 designating said bus as a conflict bus when a conflict or floating condition exists;
designating said bus as a conflict-free and float-free bus when no bus-conflict or floating
condition has been determined after evaluating all of said plurality of combinations of
logic values.

34. A method as defined in claim 33, said assigning the combination of logic values
including generating a random set of logic values.

35. A method as defined in claim 34, further including performing pre-analysis
processing comprising:

identifying all buses in said circuit design; and

arranging identified buses in sorted list for processing in which buses in the fan-in of other
5 buses appear earlier in the list than the other buses.

36. A method as defined in claim 35, said pre-analysis processing including mapping
any non-scanned pipeline flops as buffers before analyzing the buses.

37. A method as defined in claim 36, said forward simulating including performing a
parallel application of said combinations of logic values in which multiple combinations are
evaluated simultaneously by using each bit of an integer to store one combination.

38. A method as defined in claim 37, said pre-processing including:

applying of constant logic values on one or more inputs of said circuit, including assigning
and propagating said constant logic values; and

maintaining constant throughout said analyses said constant logic values and logic values
5 resulting from said propagating.

39. A program product for use in verifying a circuit logic design for proper operation of tri-state buses specified in the design, the program product comprising:

a computer readable storage medium;

means recorded on the medium for, for each bus in the circuit design, performing an

- 5 exhaustive analysis on a min-cut set of logic controlling the bus and designating each said bus as either conclusively conflict-free and float-free or as inconclusive.

40. A program product as defined in claim 39, further including means recorded on said medium for performing a full exhaustive analysis of the bus when the exhaustive analysis on

- 10 the min-cut set of logic is inconclusive.

41. A program product as defined in claim 39, said means for performing an exhaustive analysis on a min-cut set further including:

means recorded on the medium for determining a min-cut set of logic elements having the smallest size, said min-cut set being a cut-set of logic elements which separates the control logic cone of the bus into two parts in which all paths between a logic element in one part and a logic element in the other part pass through an element in the min cut-set of logic elements;

5 means recorded on the medium for determining the inputs of the min-cut set of logic elements;

- 10 means recorded on the medium for, for each of a plurality of combinations of logic values: assigning the combination of logic values to the inputs of the min-cut set of logic elements;

forward simulating the logic values from said inputs to the select inputs of each tri-state gate of the bus under test so as to determine the input of each said tri-state to said bus;

- 15 determining whether a bus-conflict or a floating bus condition exists; and designating said min-cut set exhaustive analysis as inconclusive when a conflict or floating condition exists and

means recorded on said medium for designating said bus as conflict-free and float-free

- 20 when no conflict condition has been determined after all of said plurality of combinations of logic values have been evaluated.

42. A program product as defined in claim 41 said means for assigning the combination of logic values including means recorded on said medium for generating a random set of logic values.

43. A program product as defined in claim 40, said full exhaustive analysis comprising:
means recorded on said medium for determining the inputs of the logic cone of the select
inputs of the tri-state gates of the bus under test;
means recorded on said medium for, for each of a plurality of combinations of logic values:
5 means recorded on said medium for assigning the combination of logic
values to said inputs of said logic cone;
means recorded on said medium for forward simulating said logic values from said logic
cone inputs to the select inputs of each tri-state gate of the bus under test so as to
determine the input of each said tri-state gate to said bus;
- 10 means recorded on said medium for determining whether a bus-conflict or a floating bus
condition exists;
means recorded on said medium for designating said bus as a conflict bus when a bus-
conflict or floating bus condition exists;
means recorded on said medium for designating said bus as a conflict-free and float-free
15 bus when no bus-conflict or floating bus condition has been determined after
evaluating all of said plurality of combinations of logic values.
44. A program product as defined in claim 43, said means for assigning the combination
of logic values including means recorded on said medium for generating a random set of
logic values.
45. A program product as defined in claim 39, further including means recorded on said
medium for performing pre-analysis processing comprising:
means recorded on said medium for identifying all buses in said circuit design; and
arranging identified buses in sorted list for processing in which buses in the fan-in of
5 other buses appear earlier in the list than the other buses.
46. A program product as defined in claim 45, said means for performing pre-analysis
processing including means recorded on said medium for mapping any non-scanned
pipeline flops as buffers before analyzing the buses.
47. A program product as defined in claim 45, said means for performing pre-processing
including:
means recorded on said medium for applying constant logic values on one or more inputs of
said circuit, including assigning and propagating said constant logic values; and
5 means recorded on said medium for maintaining constant throughout said analyses said
constant logic values and logic values resulting from said propagating.

48. A program product as defined in claim 41, said means for forward simulating including performing a parallel application of said combinations of logic values in which multiple combinations are evaluated simultaneously by using each bit of an integer to store one combination.

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49. A program product for use in verifying a logic design for proper operation of tri-state buses specified in the design, the program product comprising:
a computer readable storage medium;

means recorded on said medium for identifying all buses in said circuit design;

- 5 means recorded on said medium for arranging identified buses in a sorted list for processing in which buses in the fan-in of other buses appear earlier in the list than the other buses; and

means recorded on said medium for performing an exhaustive analysis on a min-cut set of logic controlling the bus, said means for performing an exhaustive analysis on a min-cut set further including:

- 10 means recorded on said medium for determining a min-cut set of logic elements having the smallest size, said min-cut set being a cut-set of logic elements which separates the control logic cone of the bus into two parts in which all paths between a logic element in one part and a logic element in the other part pass through an element in the min cut-set of logic elements;

15 means recorded on said medium for determining the inputs of the min-cut set of logic elements; and

20 means recorded on said medium for, for each of a plurality of combinations of logic values:

assigning the combination of logic values to the inputs of said min-cut set of logic elements;

forward simulating the logic values from said inputs to the select inputs of each tri-state gate of the bus under test so as to determine the input of each said tri-state gate to said bus;

25 determining whether a bus-conflict or a floating bus condition exists; and, if so, designating said min-cut set exhaustive analysis as inconclusive and performing a full exhaustive analysis of the bus;

30 means recorded on said medium for designating said bus as conflict free and float-free when no conflict conditions have been determined after evaluating all of said combinations of logic values.

50. A program product as defined in claim 49, said means for forward simulating including means recorded on said medium for performing a parallel application of said combinations of logic values in which multiple combinations are evaluated simultaneously by using each bit of an integer to store one combination.

51. A program product as defined in claim 49, said means for performing a full exhaustive analysis comprising:

means recorded on said medium for determining the inputs of the logic cone of the select inputs of the tri-state gates of the bus under test;

5 means recorded on said medium for, for each of a plurality of combinations of logic values:

assigning the combination of logic values to said inputs of the logic cone;

forward simulating the logic values from said logic cone inputs to the select inputs of each tri-state gate of the bus under test so as to determine the input of each said tri-state gate to said bus;

10 determining whether a bus-conflict or a floating bus condition exists;

designating said bus as a conflict bus when a conflict or floating condition exists;

means recorded on said medium for designating said bus as a conflict-free and

float-free bus when no bus-conflict or floating condition has been determined after evaluating all of said plurality of combinations of logic values.

52. A program product as defined in claim 51, said means for forward simulating including means recorded on said medium for performing a parallel application of said combinations of logic values in which multiple combinations are evaluated simultaneously by using each bit of an integer to store one combination.

53. A program product as defined in claim 39, further including, prior to performing an exhaustive analysis on a min-cut set of logic controlling the bus:
means recorded on said medium for performing an implication based conflict-free analysis on said bus to determine whether said bus is conflict-free;
5 means recorded on said medium for performing an implication based floating-free analysis on said bus to determine whether said bus is floating-free; and
means recorded on said medium for designating said bus as a no-conflict bus when said bus is determined to be conflict-free and floating free and selecting a next bus in sequence for analysis.
54. A program product as defined in claim 53, said means for performing an implication based conflict-free analysis on said bus to determine whether said bus is conflict-free, comprising:
means recorded on said medium for implying logic values to signals which control the control
5 input of the tri-state gate associated with said each input so as to produce an enabling control value;
means recorded on said medium for determining whether said implying logic values results in an implication conflict;
when an implication conflict exists, selecting another of said inputs and
10 repeating said means for implying and said means for determining;
when an implication conflict does not exist, determining whether said implying logic values results in a bus conflict;
terminating said implication based conflict-free analysis and
performing a full exhaustive analysis when a bus
15 conflict is determined;
means recorded on said medium for determining whether all other inputs to said bus are in a high impedance state and, if not, terminating said implication based conflict-free analysis and performing an exhaustive analysis on a min-cut set of logic controlling the bus; and
20 means recorded on said medium for designating said bus as being conflict-free when an implication conflict has been detected and as a bus conflict when an implication conflict has not been detected on said inputs of said bus.

55. A program product as defined in claim 53, said means for performing an implication based floating-free analysis on said bus to determine whether said bus is floating-free, comprising:

- 5 means recorded on said medium for implying logic values to signals which control the control input of each tri-state gate associated with said bus so as to produce disabling control value on the control inputs of said gates;
- means recorded on said medium for determining whether said implying logic values results in an implication conflict;
- 10 terminating said implication based floating-free analysis and performing an exhaustive analysis on a min-cut set of logic controlling the bus when no implication conflict is determined; and
- means recorded on said medium for designating said bus as floating-free when an implication conflict is determined.

56. A program product as defined in claim 53, said means for performing an implication based conflict-free analysis on said bus to determine whether said bus is conflict-free, comprising:

- 5 means recorded on said medium for, for each input of said bus which is controlled by a tri-state gate having a select input,
- initializing the circuit to unknown values;
- assigning an enabling value to the select input of the bus;
- implying logic values to inputs to said gate needed to produce an enabling value;
- determining whether said implying logic values results in an implication conflict and
- 10 selecting a next input for analysis when an implication conflict is detected;
- determining whether a bus conflict exists at the inputs of said bus and
- performing a full exhaustive analysis of said bus when a bus conflict exists;
- when no bus-conflict exists:
- determining whether all other inputs of said bus are in a high-
- 15 impedance state and, if not, performing said exhaustive analysis on a min-cut set of logic controlling the bus, and, if so, selecting a next input for analysis; and
- means recorded on said medium for designating said bus as conclusively conflict-free when each said implying logic values resulted in either an implication conflict all other
- 20 inputs to said bus being in a high impedance state.

57. A program product for use in verifying a logic design for proper operation of tri-state buses specified in the design, the program product comprising:
means recorded on said medium for performing an implication based conflict-free analysis on said each bus to determine whether said bus is conflict-free;
5 means recorded on said medium for performing an implication based floating-free analysis on said bus to determine whether said bus is floating-free;
means recorded on said medium for designating said bus as a no-conflict bus when said each bus is determined to be conflict-free and floating free; and
means recorded on said medium for performing an exhaustive analysis of the bus when
10 either of said implication based analyses is inconclusive.
58. A program product as defined in claim 57, said means for performing an implication based conflict-free analysis on said bus to determine whether said bus is conflict-free, comprising:
means recorded on said medium for, for each input of the bus:
5 implying logic values to signals which control the control input of the tri-state gate associated with said each input so as to produce an enabling control value;
determining whether said implying logic values results in an implication conflict;
when an implication conflict exists, selecting another of said inputs and
repeating said implying and determining steps;
10 when an implication conflict does not exist, determining whether said implying logic values results in a bus conflict and terminating said implication based conflict-free analysis and performing a full exhaustive analysis when a bus conflict is determined;
determining whether all other inputs to said bus are in a high impedance state and, if
15 not, terminating said implication based conflict-free analysis and performing an exhaustive analysis on a min-cut set of logic controlling the bus; and
means recorded on said medium for designating said bus as conclusively conflict-free when each said implying logic values resulted in either an implication conflict all other inputs to said bus being in a high impedance state.

59. A program product as defined in claim 57, said means for performing an implication based, floating-free analysis on said bus to determine whether said bus is floating-free, comprising:

- 5 means recorded on said medium for implying logic values to signals which control the control input of each tri-state gate associated with said bus so as to produce disabling control value on the control inputs of said gates;
- means recorded on said medium for determining whether said implying logic values produces an implication conflict;
- 10 means recorded on said medium for terminating said implication based floating-free analysis and performing an exhaustive analysis on said bus when no implication conflict is determined; and
- means recorded on said medium for designating said bus as floating-free when an implication conflict is determined.

60. A program product as defined in claim 58, said means for performing an implication based, floating-free analysis on said bus to determine whether said bus is floating-free, comprising:

- 5 means recorded on said medium for implying logic values to signals which control the control input of each tri-state gate associated with said bus so as to produce disabling control value on the control inputs of said gates;
- means recorded on said medium for determining whether said implying logic values produces an implication conflict;
- 10 means recorded on said medium for terminating said implication based floating-free analysis and performing an exhaustive analysis on a min-cut set of logic controlling the bus when no implication conflict is determined; and
- means recorded on said medium for designating said bus as floating-free when an implication conflict is determined.

61. A program product as defined in claim 57, said means for performing an exhaustive analysis including means recorded on said medium for performing an exhaustive analysis on a min-cut set of logic controlling the bus.

62. A program product as defined in claim 61, said means for performing an exhaustive analysis on a min-cut set including:

means recorded on said medium for determining a min-cut set of logic elements having the smallest size, said min-cut set being a cut-set of logic elements which separates the control logic cone of the bus into two parts in which all paths between a logic element in one part and a logic element in the other part pass through an element in the min cut-set of logic elements;

means recorded on said medium for determining the inputs of the min-cut set of logic elements;

10 means recorded on said medium for, for each of a plurality of combinations of logic values: assigning the combination of logic values to the inputs of the min-cut set of logic elements;

forward simulating the logic values from said inputs to the select inputs of each tri-state gate of the bus under test so as to determine the input of each said tri-state to said bus;

15 determining whether a bus-conflict or a floating bus condition exists; and designating said min-cut set exhaustive analysis as inconclusive when a conflict condition exists and

means recorded on said medium for designating said bus as conflict-free and float-free
20 when no conflict condition has been determined after all of said plurality of combinations of logic values have been evaluated.

63. A program product as defined in claim 61, said means for forward simulating including means recorded on said medium for performing a parallel application of said combinations of logic values in which multiple combinations are evaluated simultaneously by using each bit of an integer to store one combination.

64. A program product as defined in claim **61**, said means for performing an exhaustive analysis being a means for performing a full exhaustive analysis including:
means recorded on said medium for determining the inputs of the logic cone of the select inputs of the tri-state gates of the bus under test;
- 5 means recorded on said medium for, for each of a plurality of combinations of logic values:
assigning the combination of logic values to said inputs of the logic cone;
forward simulating the logic values from said logic cone inputs to the select inputs of each tri-state gate of the bus under test so as to determine
10 the input of each said tri-state gate to said bus;
determining whether a bus-conflict or a floating bus condition exists; and
designating said bus as having a no conflict bus when no conflict or floating condition exists and designating said bus as a conflict bus when a conflict or floating condition exists.
65. A program product for use in verifying a logic design for proper operation of tri-state buses specified in the design, the program product comprising, for each bus in the circuit design:
means recorded on said medium for performing an implication based conflict-free analysis on said each bus to determine whether said bus is conflict-free;
means recorded on said medium for performing an implication based floating-free analysis on said bus to determine whether said bus is floating-free; and
means recorded on said medium for designating said bus as a no-conflict bus when said bus is determined to be conflict-free and floating-free and performing an exhaustive analysis of the bus when either of said implication based analyses is inconclusive.
66. A program product as defined in claim **65**, said means for performing an exhaustive analysis including means recorded on said medium for performing an exhaustive analysis on a min-cut set of logic controlling the bus.
67. A program product as defined in claim **66**, said means for performing an exhaustive analysis including means recorded on said medium for performing a full exhaustive analysis of the bus when the exhaustive analysis on the min-cut set of logic is inconclusive.

68. A program product as defined in claim 67, said means for performing an exhaustive analysis on a min-cut set including:

means recorded on said medium for determining a min-cut set of logic elements having the smallest size, said min-cut set being a cut-set of logic elements which separates the control logic cone of the bus into two parts in which all paths between a logic element in one part and a logic element in the other part pass through an element in the min cut-set of logic elements;

means recorded on said medium for determining the inputs of the min-cut set of logic elements;

10 means recorded on said medium for, for each of a plurality of combinations of logic values: assigning the combination of logic values to the inputs of the min-cut set of logic elements;

forward simulating the logic values from said inputs to the select inputs of each tri-state gate of the bus under test so as to determine the input of each said tri-state to said bus;

15 determining whether a bus-conflict or a floating bus condition exists; and designating said min-cut set exhaustive analysis as inconclusive when a conflict or floating condition exists and

designating said bus as conflict-free and float-free when no conflict condition has been determined after all of said plurality of combinations of logic values have been evaluated.

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69. A program product as defined in claim 68, said means for performing an implication based conflict-free analysis on said bus to determine whether said bus is conflict-free comprising:

means recorded on said medium for, for each input of the bus:

- 5 implying logic values to signals which control the control input of the tri-state gate associated with said each input so as to produce an enabling control value; determining whether said implying logic values results in an implication conflict; when an implication conflict exists, selecting another of said inputs and repeating said implying and determining steps;
- 10 when an implication conflict does not exist, determining whether said implying logic values results in a bus conflict; terminating said implication based conflict-free analysis and performing a full exhaustive analysis when a bus conflict is determined;
- 15 determining whether all other inputs to said bus are in a high impedance state and, if not, terminating said implication based conflict-free analysis and performing said exhaustive analysis on a min-cut set of logic controlling the bus; and designating said bus as conclusively conflict-free when each said implying logic values resulted in either an implication conflict all other inputs to said bus
- 20 being in a high impedance state.

70. A program product as defined in claim 69, said means for performing an implication based floating-free analysis on said bus to determine whether said bus is floating-free comprising:

means recorded on said medium for initializing the circuit to unknown values;

- 5 means recorded on said medium for implying logic values to signals which control the control input of each tri-state gate associated with said bus so as to produce disabling control value on the control inputs of said gates;
- means recorded on said medium for determining whether said implying logic values produces an implication conflict;
- 10 means recorded on said medium for terminating said implication based floating-free analysis and performing an exhaustive analysis on a min-cut set of logic controlling the bus when no implication conflict is determined; and
- means recorded on said medium for designating said bus as floating-free when an implication conflict is determined.

71. A program product as defined in claim 70, said means for performing an full exhaustive analysis including:

means recorded on said medium for determining the inputs of the logic cone of the select inputs of the tri-state gates of the bus under test;

- 5 means recorded on said medium for, for each of a plurality of combinations of logic values: assigning the combination of logic values to said inputs of the logic cone; forward simulating the logic values from said logic cone inputs to the select inputs of each tri-state gate of the bus under test so as to determine the input of each said tri-state gate to said bus;
- 10 determining whether a bus-conflict or a floating bus condition exists; designating said bus as a conflict bus when a conflict or floating condition exists; designating said bus as a conflict-free and float-free bus when no bus-conflict or floating condition has been determined after evaluating all of said plurality of
- 15 combinations of logic values.

72. A program product as defined in claim 71, said assigning the combination of logic values including generating a random set of logic values.

73. A program product as defined in claim 72, further including means recorded on said medium for performing pre-analysis processing comprising:

identifying all buses in said circuit design; and

- 5 arranging identified buses in sorted list for processing in which buses in the fan-in of other buses appear earlier in the list than the other buses.

74. A program product as defined in claim 73, said pre-analysis processing including means recorded on said medium for mapping any non-scanned pipeline flops as buffers before analyzing the buses.

75. A program product as defined in claim 74, said forward simulating including means recorded on said medium for performing a parallel application of said combinations of logic values in which multiple combinations are evaluated simultaneously by using each bit of an integer to store one combination.

76. A program product as defined in claim 75, said means for pre-processing including:
means recorded on said medium for applying of constant logic values on one or more inputs
of said circuit, including assigning and propagating said constant logic values; and
means recorded on said medium for maintaining constant throughout said analyses said
5 constant logic values and logic values resulting from said propagating.

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